

Research Article

New records on the distribution of the Mexclapique, *Girardinichthys viviparus* (Bustamante, 1837) (Cyprinodontiformes, Goodeidae), an endangered species in Mexico

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Abstract

The “Mexclapique” *Girardinichthys viviparus*, is a goodeid endemic to the Valley of Mexico basin. This species is endangered following habitat alterations due to urbanization and pollution in central Mexico over the last 70 years, which has contributed to its population decline. From collections in the aquatic systems of Tlaxcala, 160 juveniles and adults of *G. viviparus* were captured (17.9–53.4 standard length) in six sites located in the upper basins of the Moctezuma and Atoyac rivers and extended its distribution to the east of the state of Tlaxcala in the Tecolutla River basin. Its presence in these sites may be the result of the processes of expansion, adaptation and establishment that the species has had in central Mexico, as well as the intercommunication through artificial channels in some of these lakes. These new records of *G. viviparus* are vital as they provide information about the prevailing populations in habitats in a region that has experimented with anthropogenic activities conjointly with the loss of aquatic systems. Besides, the lack of aquatic biodiversity preservation projects in Tlaxcala does not guarantee its long-term conservation.

Resumen

El “Mexclapique”, *Girardinichthys viviparus* es un goodeido endémico de la cuenca de México. Esta especie se encuentra amenazada debido a la alteración de su hábitat por la urbanización y contaminación en el centro del México en los últimos 70 años, lo que ha contribuido a su disminución poblacional. A partir de colectas en los sistemas acuáticos de Tlaxcala se capturaron 160 ejemplares juveniles, adultos de *G. viviparus* (17.9–53.4 longitud estándar), en seis sitios ubicados en las cuencas superiores del río Moctezuma, Atoyac y amplia su distribución al Este del estado de Tlaxcala en la cuenca del río Tecolutla. Su presencia en estos sitios puede ser resultado de procesos de expansión, adaptación y establecimiento que ha tenido la especie en el centro de México, así como a la intercomunicación mediante canales artificiales de algunos de estos lagos. Estos nuevos registros de *G. viviparus* son importantes ya que proporcionan información sobre la prevalencia de poblaciones en hábitats de una región que ha experimentado un incremento de las actividades antropogénicas y con ello la pérdida de los sistemas acuáticos. Sin embargo, la falta de proyectos de preservación de biodiversidad acuática en el estado de Tlaxcala no garantiza su conservación a largo plazo.

Key words: Endemic species, freshwater fishes, Goodeidae, Mexico basin, Tlaxcala

Palabras Clave: Cuenca de México, Especie endémica, Goodeidae, Peces dulceacuícolas, Tlaxcala

Introduction

The aquatic systems of the Mexican central highlands have supported and contributed to the diversification of flora and fauna species, including some endemic species (Ceballos et al. 2009). Twenty-two species of freshwater fish have been reported in the Mexico Basin, seven of them invasive, three extinct species (Genus *Evarra*) and three extirpated, i.e., they have no established populations in their natural habitat; *Notropis sallaei* (Günther, 1868), *Algansea tinicella* (Valenciennes, 1844), *Chirostoma humboldtianum* (Valenciennes, 1835) (Contreras-Balderas et al. 2008; Huidobro-Campos et al. 2016). Among the native fish that still survive in central Mexico is the “Mexclapique” *Girardinichthys viviparus* (Bustamante, 1837).

The genus *Girardinichthys* (Family Goodeidae) is distributed and endemic to the central Mexican highlands and is comprised of four species: *G. viviparus*, *G. irenae* Radda & Meyer, 2003, *G. multiradiatus* (Meek, 1904) and *G. turneri* (de Buen, 1940) (Lyons et al. 2019). These species are at risk since most of their populations have become extinct or considerably reduced due to the degradation of aquatic systems, pollution, introduction of exotic species and land use change (Navarrete-Salgado et al. 2004; Gómez-Márquez et al. 2013).

The species *Girardinichthys viviparus*, usually known as “Mexclapique” or Chapultepec splitfin, is distributed in the endorheic basin of the Valley of Mexico and geopolitically corresponds to Mexico City and part of the states of Mexico, Hidalgo, and Tlaxcala (Navarrete-Salgado et al. 2004; Miller et al. 2009; Koeck 2019). This endemic species was abundant in many regional lakes and wetlands of the Mexico basin; however, the decrease and disappearance of several populations have been identified, and currently, only 2% of the natural aquatic landscape of this region is preserved (Legorreta et al. 2009).

In 1957, there were records in 17 localities in the Valley of Mexico (Álvarez del Villar and Navarro 1957); by 1976, there were still populations in Lake Zumpango, and in 1977, the last known collections of this species were made in San Juan Teotihuacán, State of Mexico (Miller et al. 2009). Vega-López et al. (2007) and Sedeño-Díaz and López-López (2009) did not find this species in Lake Zumpango, and its absence is attributed to aquatic pollution. Domínguez-Domínguez et al. (2005a) mention that this species disappeared from Lake Chalco and Texcoco. However, some specimens were found that survived and were cultivated under an initiative of the hydrological rescue of Lake Texcoco (Cruickshank-García 1995; DOF 2022).

The last populations and records of *G. viviparus* in the last 20 years correspond to the lakes of Chapultepec Park, Alameda oriente, and Xochimilco in Mexico City, in Lake Nabor Carrillo and Tecocomulco in the states of Mexico and Hidalgo, respectively (Navarrete-Salgado et al. 2004; Vega-López et al. 2007; Miller et al. 2009; Gómez-Márquez et al. 2013; Vázquez-Silva et al. 2017; Lyons et al. 2019).

These urban aquatic systems are used as recreational sites and differ from natural lakes as they are shallow, artificial and hypertrophic systems with variable physicochemical conditions (16–25 °C, dissolved oxygen range from 0.63 to 24.9 mg/L, pH 3.1–9.8) due to the input of wastewater subjected to purification processes to reduce pollutants (Navarrete-Salgado et al. 2004; Miranda et al. 2008; Gómez-Márquez et al. 2013).

The “Mexclapique” is tolerant to these environmental pressures and conditions, and its populations are higher when not associated with other fish. However, it is a viviparous fish with a low birth rate. In addition, environmental pressure, habitat disturbance, limited dispersal, and recolonization capacity influence the vulnerability of this species (Domínguez-Domínguez et al. 2005b; Huidobro-Campos et al. 2016). These factors have contributed to this species being listed in the “threatened” category according to national risk criteria (SEMARNAT 2010) and as “endangered” according to the IUCN (Koeck 2019).

The lacustrine area in the northeastern part of the Mexico Basin includes the “Llanos de Apan” region, a semi-arid zone with a predominantly plain relief, together with climatic conditions that have led to the absence of perennial water currents (Galindo-Escamilla 2007). However, bodies of water such as the lakes of Tecocomulco, Apan, and Tochac, together with the lakes of Atlangatepec and Acuitlapilco, are the most essential aquatic systems in the State of Hidalgo and Tlaxcala due to their size and biodiversity (Lara-Rodríguez 2015).

In the surroundings of the lakes, seasonal agriculture, and farming activities are developed, which has increased population growth and urban development, thus increasing the contribution of wastewater to these aquatic systems (Huizar-Álvarez et al. 1997; Mena-Mejía et al. 2017). However, the effects of pollutants, composition, and dynamics of fish in these lakes are unknown because knowledge of the ichthyofauna of Tlaxcala is scarce.

From collections carried out to identify the ichthyofauna present in the state of Tlaxcala, we report new records of populations of the “Mexclapique” *Girardinichthys viviparus* in the Upper Atoyac, Moctezuma, and Tecolutla River basins.

Methods

Collections were carried out in Tlaxcala state, around Lake Tochac and Atlangatepec, Tenexac dam, and “jagüeyes” from February 2019 to June 2021 (Figs 1–3) using a trawling net with a 2 m long and 1 cm mesh size, a sample of *Girardinichthys viviparus* specimens were captured to corroborate their identity at a specific level with the help of specific literature (Miller et al. 2009; Lyons et al. 2019).

Specimens were fixed in formalin (10%), preserved in ethanol (70%), and deposited in the Ichthyological Collection of the Facultad de Estudios Superiores Iztacala of the Universidad Nacional Autónoma de México (catalog numbers: CIFI 1505, CIFI 1598, CIFI 1708, CIFI 1710, CIFI 1711). Primary meristic and morphometric meristic data were obtained from them with a caliper (mm), total length (TL), and standard length (SL) (Fitzsimons 1972) (Table 1).

Table 1. Meristic and morphometric data specimens of “Mexclapique,” *Girardinichthys viviparus*, inhabit the aquatic systems of Tlaxcala, Mexico.

MORPHOMETRIC DATA (mm)	CIFI-1505 n = 21	CIFI-1598 n = 13	CIFI-1708 n = 31	CIFI-1709 n = 75	CIFI-1710 n = 13	CIFI-1711 n = 7	Mean values (Min–Max)
Total length	22.4–43.3	23.6–68.8	26.7–57	26.4–36.1	25.7–36.9	23.8–37.7	24.7–46.6
Standard length	20.9–36.5	18.6–53.4	21.5–48.2	21.6–29.2	20.9–29.5	17.9–31.2	20.2–38
Cephalic length	6.6–10.7	6.4–14	6.6–13.1	5.3–7.5	6.2–7.5	4.6–9.1	5.9–10.3
Ocular diameter	2.4–3.2	2.4–3.1	2.3–3	1.9–2.3	2–2.1	1.6–2.8	2.1–2.7
Snout length	0.9–19	0.5–4.3	1.7–2.5	0.9–1.4	1.1–1.3	0.8–2.1	0.98–5.1
Predorsal length	11.5–20.9	11.3–31.8	11.9–29.3	11.5–15.5	11.8–15.5	10.1–17.2	11.3–21.7
Preanal length	11.3–22.2	11.8–37.8	12.4–34.1	17.2–19	12.9–17.3	12.2–17.9	12.9–24
Body height	5.6–11.9	4.9–21.8	15.8–16.7	5.8–8.1	6.8–9.9	5.8–9.6	7.4–13
MERISTIC DATA							
Dorsal fin rays	19–22	19–21	21–24	23–26	20–26	20–26	20–24
Anal fin rays	21–24	23–25	21–23	24–28	23–29	22–29	22–26
Caudal fin rays	20–21	19–20	18–19	18–20	18–21	20–20	18–20
Scales with pore on lateral line	48–53	48–50	48–52	45–55	54–60	52–56	49–54

Results

A total of 160 juvenile and adult specimens of *Girardinichthys viviparus* (17.9–53.4 SL, 23.8–68.8 TL) were collected at six sites in central (Atlangatepec Lake; Jagüeyes), northwest (Tochac Lake), and eastern (Tenexac dam) of Tlaxcala state, located in the upper basins of the Atoyac, Moctezuma, and Tecolutla rivers (Fig. 1). Specimens are characterized by the following features: a slender body and caudal peduncle (34–37% SL); the base of the dorsal and anal fins in males, approximately the same length as the base of the anal; small eye with a proportion of 26–35% of the cephalic length (CL); dorsal fin with 19 to 26 rays; anal fin with 21 to 29 rays; scales on the lateral line 45–55 (Table 1).

The body coloration is green-olivaceous, slightly hyaline, and on the sides, an iridescent horizontal line runs along the body from the postorbital region to the base of the caudal peduncle (Fig. 2). Melanophores are scattered throughout the body, with a more significant presence in the cephalic region and dorsal and anal fins. The abdominal area is white, iridescent peritoneum, with a lower jaw and operculum iridescent (Fig. 2C, D, F). Males have dark coloration between the dorsal and anal fin rays, sometimes intense black spots on the dorsal fins, as well as hyaline coloration on the periphery of both fins (Fig. 2C, D). These fish have a caudal fin with a faint yellow-greenish coloration at the base of the fin, while females show a slightly fainter coloration over the whole body.

The specimens of *G. viviparus* collected were both the juvenile and reproductive adult stages. Females are characterized by a larger size than males. Adult females were identified with a prominent bulge in the abdominal area, indicating a reproductive state [CIFI 1708 (4 gravid females), CIFI 1710 (7), CIFI 1711 (1)]. Embryos at an advanced stage of development were identified in two gravid females (CIFI 1598; Fig. 2A) and 23 adult females, eight of them with embryos at some stage of development (CIFI 1709). The CIFI 1505 records five adult females without signs of pregnancy.

Class Actinopteri
Order Cyprinodontiformes
Family Goodeidae

***Girardinichthys viviparus* (Bustamante, 1837)**

Figs 1–3

Material collected. MEXICO: CIFI 1505, 21 ind., 20.9–36.5 mm SL, Atlangatepec Lake, Atlangatepec municipality, Atoyac River basin, 19°32'58.2"N, 98°10'32.5"W, 18 Feb 2019, Col. Perez-Díaz, J.; CIFI 1708, 31 ind., 21.5–48.2 mm SL, Tochac Lake, borderline of the municipality of Benito Juárez, Tlaxcala and San Antonio Atocha, Hidalgo, Moctezuma River basin, 19°36'58.3"N, 98°26'46.2"W, 20 Jun 2019, Col. Pérez-Díaz, J., Perez-Díaz, Y.A., Hernández-Arellano, T., López-Segovia, E.; CIFI 1598, 13 ind., 18.6–53.4 mm SL, Tenexac reservoir, Terrenate municipality, Tecolutla River basin, 19°30'03.6"N, 97°58'50.6"W, 7 Mar 2020, Col. Pérez-Huerta, J.A., Pérez-Díaz, J., López-Segovia, E.; CIFI 1709, 75 ind., 21.6–29.2 mm SL, Tenexac reservoir, Terrenate municipality, Tecolutla River basin, 19°30'05.5"N, 97°58'51.4"W, 18. Jul 2020, Col. Pérez-Díaz, J., Hernández-Arellano, T., Del Moral-Flores, L.F., López-Segovia, E.; CIFI 1710, 13 ind., 20.9–29.52 mm SL, "Jagüey", near Atlangatepec Lake, Loma Bonita, Atlangatepec municipality, Atoyac River basin, 19°31'53.6"N, 98°12'56.8"W, 19 Jul 2020, Col. Pérez-Díaz, J., Hernández-Arellano, T., Del Moral-Flores, L.F., López-Segovia, E.; CIFI 1711, 7 ind., 17.9–31.2 mm SL, Atlangatepec Lake, Atlangatepec municipality, Atoyac River basin, 19°33'24.6"N, 98°12'08.9"W, 19 Jul 2020, Col. Pérez-Díaz, J., Hernández-Arellano, T., Del Moral-Flores, L.F., López-Segovia, E.

Discussion

The great lakes of the Valley of Mexico have developed changes or disappeared due to intense geological activity in the region and anthropogenic alterations in central Mexico (Huizar-Álvarez et al. 1997; Jiménez et al. 2003; de la Lanza-Espino and Gómez-Rodríguez 2005). The northeastern limits of this basin are not well defined since a series of plains and low slopes mark the border with several neighboring endorheic sub-basins, such as Tecocomulco, Apan, and Tochac (Calderón de Rzedowski and Rzedowski 2005), the lakes of these basins relicts of the basin of Mexico (Huizar-Álvarez et al. 1997; Jiménez et al. 2003; de la Lanza-Espino and Gómez-Rodríguez 2005).

The natural conditions of watershed runoff have been modified over time due to the expansion of urban areas, and therewith the modification and drastic decrease of *G. viviparus* populations since the second half of the 20th century (DOF 2015a; Lyons et al. 2019). The construction of the great drainage canal and the "Tequisquiac" tunnels at the end of the 19th century to drain the Valley of Mexico towards the Tula River reduced Lake Texcoco to a series of interconnected and isolated lakes so that *G. viviparus* has been recorded in the upper basin of the Río Pánuco, Hidalgo (Álvarez del Villar and Navarro 1957; Miranda et al. 2008; Lyons et al. 2019; Cordova et al. 2021).

In turn, Lake Tochac drains its waters into the Apan lagoon, which is intercommunicated with Lake Tecocomulco, considered the recharge area to the adjacent aquifers, which, through artificial canals, discharge their waters into the Zump-

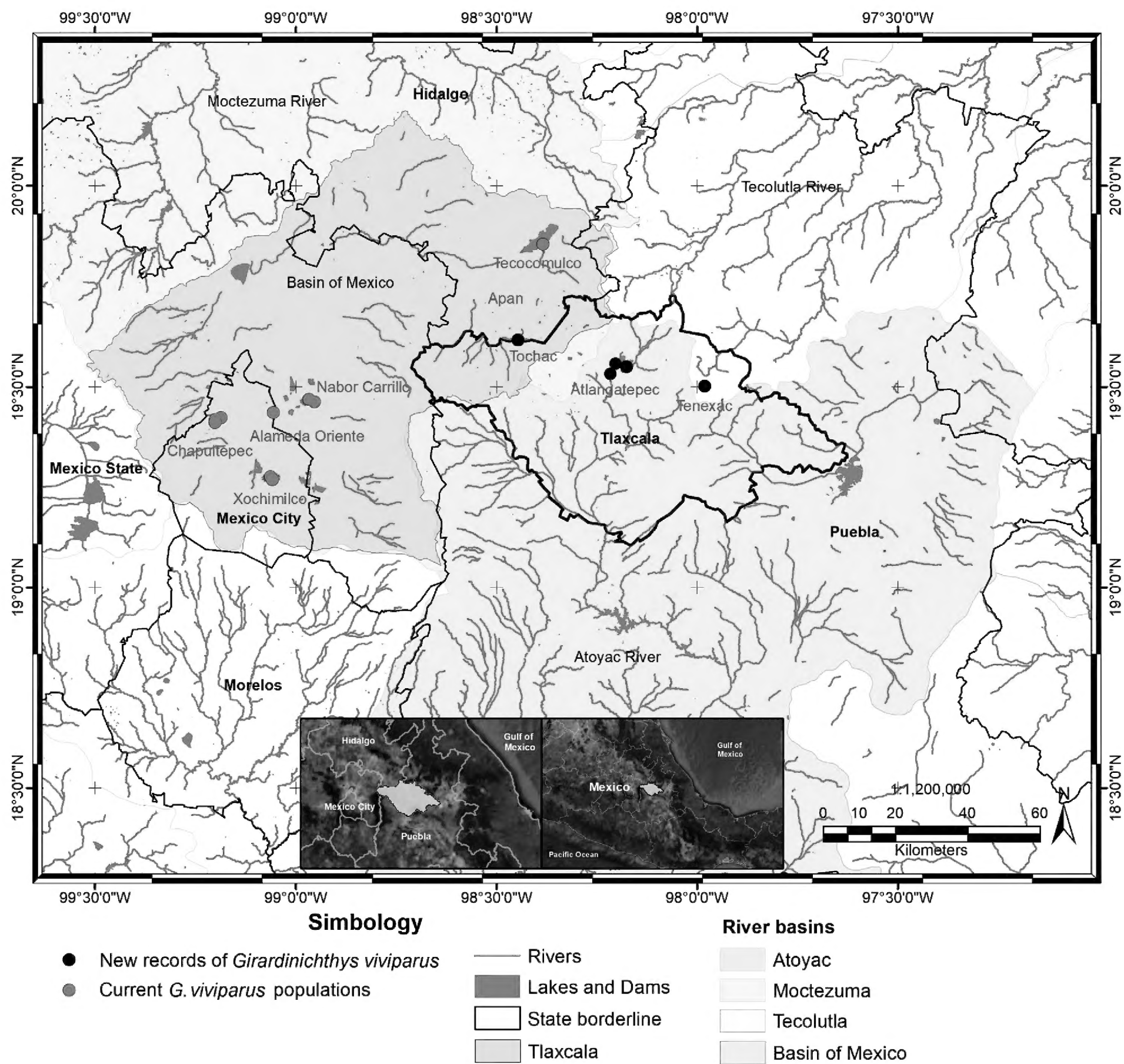


Figure 1. New records of *Girardinichthys viviparus* in Tlaxcala and current distribution in the basin of Mexico.

ango region (DOF 2015a; Huízar-Álvarez et al. 2001). The connection between these aquatic systems could explain the presence of *G. viviparus* in Lake Tochac. Lake Atlangatepec is the reservoir with the largest water surface area in the state of Tlaxcala and important in the Atoyac-Zahuapan irrigation district; however, its main tributary, the Zahuapan River, is also the main source of contamination due to the discharge of water from urban and industrial use (Pérez-Rodríguez and Badillo-Solís 1996; Salomón-Serna et al. 2003; Villordo 2011). Exotic fish species were introduced into this lake, which was provided by the Ministry of Environment and Natural Resources through the Atlangatepec Aquaculture Center since 1987 with the continuous production of hatchlings that are supplied to different reservoirs in Tlaxcala (Salomón-Serna et al. 2003; CONAPESCA 2008).



Figure 2. Specimens of *Girardinichthys viviparus* were collected in Tlaxcala (photographed *in situ*). Female (**A**) and male (**B**) specimens from Tenexac dam (CIFI 1598, 18.6–53.4 mm SL); male specimens (**C**, **D**) from the “jagüey”, Loma Bonita, Atlangatepec (CIFI 1710, 20.9–29.5 mm SL; female specimen (**E**) from Tochac Lake, (CIFI 1708, 21.5–48.2 mm SL); and male specimen (**F**) from Atlangatepec Lake (CIFI 1711, 17.9–31.2 mm SL). The scale bar: 1 cm.

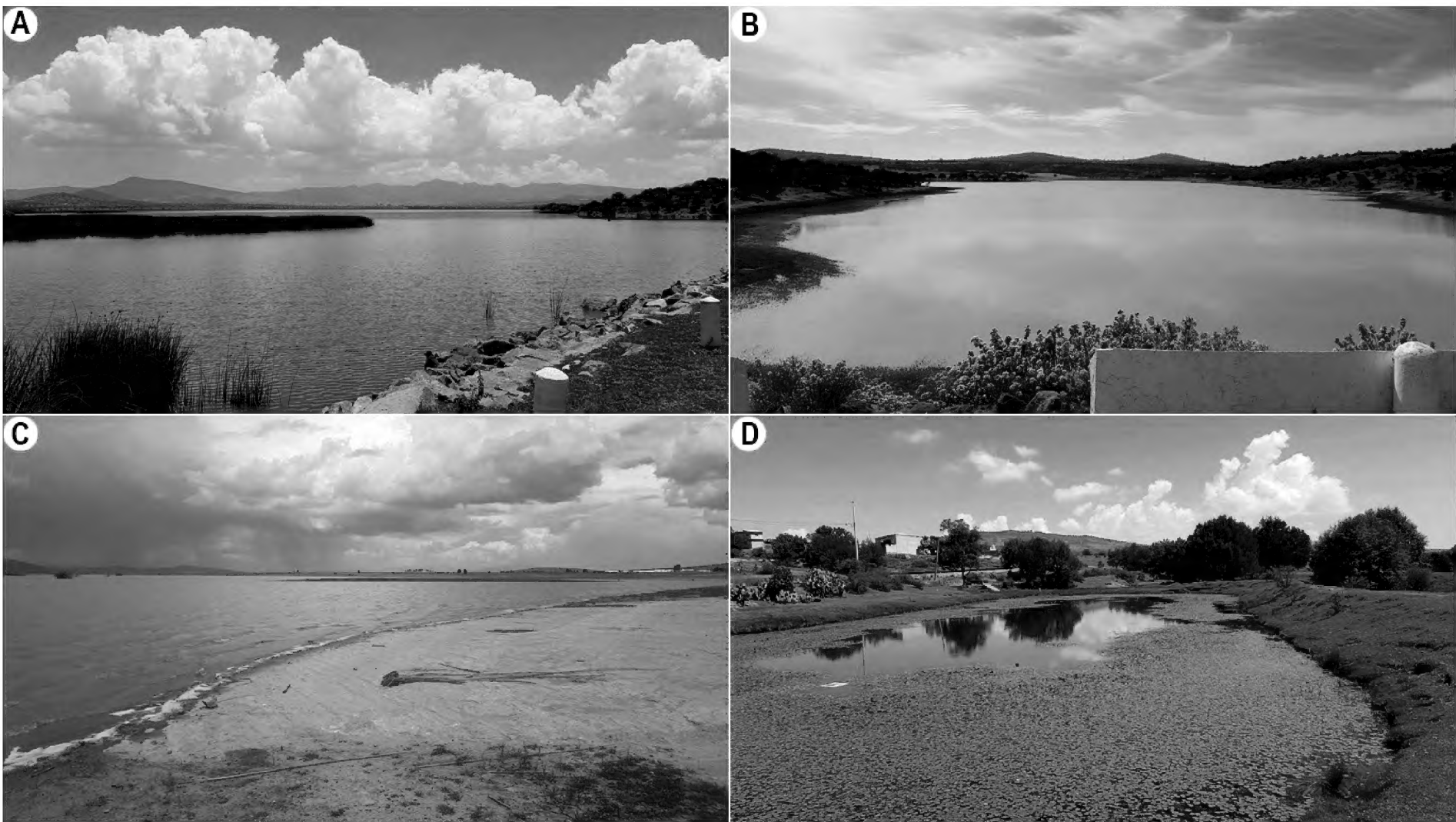


Figure 3. Aquatic systems where *Girardinichthys viviparus* inhabits the state of Tlaxcala **A** Atlangatepec Lake **B** Tenexac Dam **C** Tochac Lake **D** “Jagüey” in the locality of Loma Bonita, Atlangatepec.

Among the exotic species used in the local fishery is the carp of the Cyprinidae family; *Cyprinus carpio* Linnaeus 1758 and there are records in Lake Atlangatepec of translocated Mexican species such as the “Charal” *Chirostoma jordani* Woolman 1894 (Fam. Atherinopsidae) and *Algansea lacustris* Steindachner 1895 (Fam. Leuciscidae) although these species are not very abundant (Bermúdez-Rodríguez et al. 2002; Rodríguez-Gutiérrez et al. 2021). There is only one record of *G. viviparus* in this lake, but there is no information on the survival of this species at this site (Fernández-Crispín 1990).

In contrast to Lake Tochac and Atlangatepec, the Tenexac dam was built in the Tecolutla river basin to provide water supply for agricultural and irrigation activities in the region (DOF 2015b). However, there is no information on the physical-chemical conditions and aquatic fauna in this aquatic system; it has only been identified that *G. viviparus* shares this habitat with the exotic carp *C. carpio* and the plateau tiger salamander *Ambystoma velasci* (Flores-Márquez 2005; Pérez-Díaz et al. 2020).

The presence of *G. viviparus* in the Atlangatepec, Tochac, and Tenexac lakes and “jagüeyes” in the upper basins of the Atoyac, Moctezuma and Tecolutla rivers in Tlaxcala may be a response to evolutionary processes of expansion, adaptation and establishment of the species in central Mexico (Foster and Piller 2018; Caballero-Viñas et al. 2023). Another hypothesis could be establishing this species as a fauna to accompany the planting of invasive species in the lakes and “jagüeyes” in which they have adapted.

The “jagüeyes” similar to ponds, are systems for catchment and storage of runoff and rainwater in rural areas that represent 96% of the water bodies in Tlaxcala and are used to supply water for human consumption, and agricultural, and livestock activities, and are also crucial for the subsistence of the scarce aquatic fauna (González-Jacomé 2013; Briones-Pérez et al. 2017; López-Segovia et al. 2023). However, they are susceptible to their disappearance due to lack of maintenance, drying up due to rainfall deficits, land use changes, or extension of agricultural and industrial zones (Galindo-Escamilla 2007). In addition, many “jagüeyes” are located near roads or main highways and are therefore susceptible to contamination by waste accumulation, a scenario that keeps *G. viviparus* populations at risk.

Urbanization processes and agricultural and livestock activities in Tlaxcala negatively modify the physicochemical and ecological conditions of the lakes, contributing to their eutrophication, toxicity and pollution (Flores-Márquez 2005; SAGARPA 2014). An example of this is the high levels of phosphates in the sediments due to the use of fertilizers in agricultural crops around Lake Tochac, which generates poor water quality conditions that can affect the fish used in aquaculture in these sites (Quiroz-Flores et al. 2018; Pérez-Sánchez 2019). Another problem is freshwater extraction and grabbing for domestic and industrial demand, which, together with pollution and land use change, have fragmented the distribution of *G. viviparus*, keeping its populations vulnerable (Serrano-Meneses 2015; Lyons et al. 2019).

These factors have contributed to the disappearance of fishes in the center of the country, such as the *Evarra* genus, whose species became extinct due to the drying up of the canal system in Mexico City (Contreras-Balderas et al. 2002; Mejía-Guerrero 2019). Similarly, endemic species of the genus *Characodon*, *Cyprinodon*, and *Stypodon* that inhabited springs in the endorheic basins of northern Mexico became extinct due to the overexploitation of aquifers by agriculture and mining activities (Miller et al. 1989; Lozano-Vilano and Contreras-Balderas 1993).

However, the future of *G. viviparus* populations and aquatic biodiversity in Tlaxcala is uncertain due to negative impacts, lack of management plans, and projects for conserving aquatic systems in the medium and long term by local government authorities to ensure the preservation of native fish.

Conclusions

The new records of *Girardinichthys viviparus* provide information on the new habitats that this species is occupying, thus expanding and updating the distribution of this goodeid in the aquatic systems of central Mexico. However, we recommend sustainable management, capture methods, and selective fishing of introduced exotic species in lakes and ponds to minimize the impact on vulnerable species.

We suggest that local educational and research institutions continuously monitor and analyze the ecology, biology, and abundance of *G. viviparus* as well as physicochemical factors (pH, dissolved oxygen, contaminants) in Tenexac Lake, Atlangatepec, Tochac, and "jagüeyes". These studies would provide crucial data for the implementation of effective conservation measures.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Conceptualization: ELS, JPD. Data curation: JPD. Formal analysis: ELS, LFD MF, JPD, THA. Investigation: ELS, LFD MF. Methodology: JPD, THA. Supervision: LFD MF. Visualization: ELS, LFD MF. Writing - original draft: ELS. Writing - review and editing: LFD MF, JPD, THA. English review. THA.

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Data availability

All of the data that support the findings of this study are available in the main text.

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